AN ULTRASONIC NON-DESTRUCTIVE TESTING METHOD FOR EVALUATING RESISTANCE SPOT WELDING QUALITY

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ABSTRACT

The resistance spot welding is a major method for joining sheet metals in high-speed train manufacturing industry. The accuracy and rapidity of evaluating the resistance spot welding quality is the key point of ensuring the manufacturing quality and running safety of the high-speed train. In this paper, a Nondestructive Testing (NDT) system is set up based on ultrasound pulse-echo method for detecting manufacturing defects and measuring the indentation depth and nugget diameter of resistance spot welding. In order to verify the accuracy of indentation depth and nugget diameter measured by the NDT system, the inspection results are compared with metallographic analysis. In addition, the resistance spot welding indentation depth of some resistance spot welding samples are analyzed before and after increasing the welding energy, the results show that increasing the welding energy can improve the welding quality.

KEYWORDS: Resistance spot welding inspection, ultrasound, Pulse-echo method

1. INTRODUCTION

Resistance spot welding is an important welding technique that has been considered as the dominant process for joining sheet metals in high-speed railway industry due to its high production efficiency and adequacy for the automated realization [1-2]. The indentation depth and nugget diameter of the resistance spot welding are the main critical parameters that influence the quality of the resistance spot welding. The indentation depth of resistance spot welding is generally hidden between two sheets, the formation and expansion of nugget are in a closed state and cannot be directly observed, which implies difficulties regarding the detection of resistance spot welding [3-4]. Therefore, the accurate measurement of the indentation depth and nugget diameter is the key step for evaluating the quality of resistance spot weldings [5-6].

At present, in actual production, the main quality assessment methods of the welding spots are the destructive chisel test and peel test. However, both methods are rather time consuming [7-8]. In recent years, many research works focused on applying nondestructive testing methods to address this problem. Compared with other NDT techniques, ultrasonic technology is much more attractive due to its high sensitivity, wide test range, high test speed, good safety performance and convenience for on-site site operation [9]. In this paper, an ultrasonic test method is presented, where we use C-Scan image to measure indentation depth and nugget diameter of the resistance spot welding, then the resistance spot welding indentation depth of some resistance spot welding samples are analyzed before and after increasing welding energy.
2. METHOD

The pulse-echo method by using high frequency contact probe is shown in Fig.1. The ultrasonic wave is reflected by the interface with different acoustic impedance, and the ultrasonic wave characteristics can be used to analyze the defect parameters.

![Fig.1 The pulse-echo method for resistance spot welding defects inspection.](image)

The resistance spot welding indentation depth computing method is shown in Fig.2, and the resistance spot welding indentation depth \( C \) can be computed using the following equation: \( C = \frac{(S_2 - S_1)}{2} = \frac{V \times \Delta t}{2} \), where \( V \) is the velocity of ultrasonic waves in water, \( \Delta t \) is the time difference between \( S_2 \) and \( S_1 \).

![Fig.2 The resistance spot welding indentation depth computing method.](image)

In the C-scan image of the interfacial layer in the resistance spot welding samples, the area of the nugget zone was found to calculate the value of the nugget diameter. The diameter computing method of the resistance spot welding nugget is shown in Fig.3, and the resistance spot welding nugget diameter \( D = 2 \times (S/\pi)^{1/2} \), where \( S \) is the nugget area.
3. Experimental Setup

3.1 SAMPLES

Resistance spot welding samples with three-layer plate structure are shown in Fig.4. The length and width of each layer plate are 160mm and 75mm while the thicknesses of each layer are 2 mm, 1.5 mm and 4 mm, respectively. The sample material is stainless steel with different welding parameters. The details of these samples are shown in Table 1, which is provided by Qingdao SiFang Co., LTD, China.
Table 1 Welding process parameters of resistance spot welding samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Welding current/A</th>
<th>Number of pulses</th>
<th>Power on time/ms</th>
<th>Compress time/ms</th>
<th>Electrode pressure/ kPa</th>
<th>Cooling time/ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.0-9.9-9.9</td>
<td>3</td>
<td>400-480-480</td>
<td>1800</td>
<td>8</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>10.2-10.2</td>
<td>2</td>
<td>440-440</td>
<td>1800</td>
<td>8</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>10.9-10.9</td>
<td>2</td>
<td>540-540</td>
<td>1800</td>
<td>8</td>
<td>200</td>
</tr>
</tbody>
</table>

3.2 INSPECTION SYSTEM

Using the water immersion focusing method, the resistance spot welding nondestructive testing system is set up as shown in Fig.5 (a). The resistance spot welding NDT system includes two parts: portable all-in-one PC and detection mechanism as shown in Fig.5 (b). The portable all-in-one PC is composed of a data acquisition card, a pulse generator, two data processors (one CPU and one MCU), a driver and a controller. The pulse generator is used to excite the probe and the encoder, the data acquisition card is used to obtain the ultrasonic data. The detection mechanism includes an encoder, a stepping motor, a gearing-down and a probe. The stepping motor controls probe movement and the encoder is used to send position signal to the pulse generator. The ultrasound wave frequency is 15 MHz.

![Fig.5 The resistance spot welding nondestructive testing system.](image)
4. RESULT AND DISCUSSION

4.1 INDENTATION DEPTH AND NUGGET DIAMETER DETECTION

The measurement results obtained via the NDT system when inspecting Sample 1 is shown in Fig.6, Fig.6 (a) shows the vertical oriented B-scan, Figure 6(b) is the B-scan, Fig.6(c) is the C-scan of the 1-2 layer interface, and Fig.6(d) is the C-scan of the 2-3 layer interface.

Fig.6 The measurement results of Sample 1.

Similarly, Fig.7 and Fig.8 are the measurement results of Sample 2 and Sample 3. The measured indentation depths and nugget diameters of each sample based on the NDT images are listed in Table 2.

Fig.7 The measurement results of Sample 2.
Figure 7. The measurement results of Sample 3.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Indentation depth</th>
<th>1-2 layer nugget diameter</th>
<th>2-3 layer nugget diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.06mm</td>
<td>12.78mm</td>
<td>13.05mm</td>
</tr>
<tr>
<td>2</td>
<td>0.06mm</td>
<td>14.37mm</td>
<td>13.25mm</td>
</tr>
<tr>
<td>3</td>
<td>0.08mm</td>
<td>15.22mm</td>
<td>14.45mm</td>
</tr>
</tbody>
</table>

Table 2 Test results of resistance spot welding nondestructive testing system.

Next and in order to verify the accuracy of indentation depth and nugget diameter measured by the resistance spot welding nondestructive testing system, the test results are compared with a metallographic analysis. The metallographic photographs of the three samples are shown in Fig.8, and the results of metallographic analysis are shown in Table 3.

Fig.8 The metallographic analysis of the resistance spot welding samples. (a)Sample1 (b) Sample 2 (c) Sample 3
<table>
<thead>
<tr>
<th>Sample</th>
<th>Indentation depth</th>
<th>2-3 layer nugget diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.60mm</td>
<td>9.36mm</td>
</tr>
<tr>
<td>2</td>
<td>0.50mm</td>
<td>9.58mm</td>
</tr>
<tr>
<td>3</td>
<td>0.09mm</td>
<td>12.05mm</td>
</tr>
</tbody>
</table>

Table 3 Test results of resistance spot welding metallographic analysis.

There are three main factors affected the measurement. Firstly, the surface of the sample is not flat, so the ultrasonic wave cannot reach the maximum indentation depth when the reflection occurs, thus the test result is small. Secondly, when cutting the metallographic sample, it is hard to make sure that the cutting surface just passes the maximum fusion diameter, which results in certain differences in the test results. Thirdly, the plate gap near the heat affected zone is so small that the upper and lower plates partially form common grains. When the ultrasonic testing is performed, the wave signal directly penetrates into the lower plate, and the reflected echoes cannot be formed at the plate interface. As a result, the measured nugget diameter is larger than the actual size.

4.2 IMPROVEMENT OF WELDING QUALITY

Based on the resistance spot welding nondestructive testing system, the resistance spot welding horizontal and vertical indentation depth before the increase of welding energy are computed as shown in Fig.9 (a). The average of resistance spot welding vertical indentation depth is 0.1649mm, and the variance of it is 0.0079. Correspondingly, the average of resistance spot welding horizontal indentation depth is 0.2510mm, and the variance of it is 0.0702. The fluctuation of resistance spot welding horizontal indentation depth is larger than that of resistance spot welding vertical indentation depth, which means that the resistance spot welding is probably lean. The spot weld horizontal and vertical indentation depth after the increase of welding energy is computed as shown in Fig.9 (b). The average of spot weld vertical indentation depth is 0.155 mm and the variance of it is 0.00438. Correspondingly, the average of spot weld horizontal indentation depth is 0.1926 mm and the variance of it is 0.1526. The fluctuation of resistance spot welding horizontal indentation depth is partially larger than that of resistance spot welding vertical indentation depth, however less fluctuations is remarked compared to Fig. 9 (a). As it can be noticed, the average and variance of the spot weld indentation depth after increasing welding energy is larger than that of the spot weld horizontal and vertical indentation depth before increasing welding energy. Thus the welding quality is improved and the quality fluctuation is rather decreased.
Fig.9 The spot weld horizontal and vertical indentation depth before and after increasing welding energy. The number of samples is represented in the X axis and the indentation depth is represented in Y axis. (a) The spot weld horizontal and vertical indentation depth before increasing welding energy. (b) The spot weld horizontal and vertical indentation depth after increasing welding energy.

3. CONCLUSION

To evaluate the quality of resistance spot welding, an ultrasonic non-destructive testing system of resistance spot welding based on ultrasonic C-scan method is set up. Through the processing of the echo signals, the indentation depth and the nugget diameter of the resistance spot welding sample can be measured, and potential defects could be detected. Through the analysis of the test results and the metallographic experimental verification, the results show that the resistance spot welding NDT system can detect the indentation depth and the nugget diameter with a certain deviation within an allowable range. The horizontal and vertical welding indentation depth of the resistance spot before and after increasing welding energy were measured, the fluctuation of horizontal indentation depth of resistance spot welding is hereby larger than that of vertical indentation depth. In addition, it was shown that the welding quality is improved and the quality fluctuation is decreased by increasing of the welding energy which helps improving the manufacturing quality.

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